

# Magnetoresistance and magnetic anisotropy in $\text{La}_{0.5}\text{Sr}_{0.5}\text{CoO}_{3-\delta}$ film

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The magnetic and transport properties of  $\text{La}_{0.5}\text{Sr}_{0.5}\text{CoO}_{3-\delta}$  film grown on a  $\text{LaAlO}_3$  substrate by pulsed-laser deposition are studied. The properties are found to be influenced by a combined influence of the magnetic anisotropy and inhomogeneity. Magnetoresistance anisotropy is determined by the shape anisotropy and the strain-induced magnetic anisotropy due to the film-substrate lattice interaction. Indications of the temperature-driven spin reorientation transition from an out-of plane ordered state at low temperatures to an in-plane ordered state at high temperatures as a result of competition between the mentioned anisotropy sources are found.

## 1. INTRODUCTION

Hole-doped lanthanum cobaltates of the type  $\text{La}_{1-x}\text{Sr}_x\text{CoO}_3$  have attracted much attention in recent years due to their unique magnetic and transport properties [1,2]. Study of this system is also important for understanding the nature of colossal magnetoresistance in the related oxides, doped manganites [3]. For technical application, the epitaxial films of these compounds are mainly implied to be used. In that case the shape anisotropy and the film-substrate lattice interaction can induce magnetization anisotropy and, therefore, magnetoresistance (MR) anisotropy (bulk samples of these compounds show no marked magnetic and MR anisotropy). This point was studied rather intensively in manganite films (see [4] and references therein), but it is hardly to find in literature some studies of this type for doped cobaltates. Beside this, the properties of doped cobaltates are influenced by their (extrinsic and intrinsic) magnetic inhomogeneity. In this report we present a study of  $\text{La}_{0.5}\text{Sr}_{0.5}\text{CoO}_{3-\delta}$  film which demonstrates a combined influence of the magnetic anisotropy and inhomogeneity on its transport and magnetic properties.

## 2. EXPERIMENTAL

The  $\text{La}_{0.5}\text{Sr}_{0.5}\text{CoO}_{3-\delta}$  film (about 220 nm thick) was grown by pulsed-laser deposition (PLD) on a (001) oriented  $\text{LaAlO}_3$  substrate. The ceramic target used was prepared by a standard solid-state reaction technique. A PLD system with an Nd-YAG laser operating at  $1.06 \mu\text{m}$  was used to ablate the target. The pulse energy was about 0.39 J with a repetition rate of 12 Hz and pulse duration of 10 ns. The film was deposited with a substrate temperature of  $880 \pm 5^\circ\text{C}$  in oxygen atmosphere at a pressure of about 8 Pa. The film was cooled down to room temperature after deposition at an oxygen pressure about  $10^5$  Pa. The target and film were characterized by X-ray diffraction (XRD) study.

The film resistance, as a function of temperature and magnetic field  $H$  (up to 20 kOe), was measured using a standard four-point technique. The field was applied parallel or perpendicular to the film plane. In both cases it was perpendicular to the transport current. The magnetization,  $M$ , was measured in a Faraday-type magnetometer.

## 3. RESULTS AND DISCUSSION

Temperature dependences of the film magnetization for the field directions parallel  $[M_{\parallel}(T)]$  and perpendicular  $[M_{\perp}(T)]$  to the film plane are shown in Fig. 1. The Curie temperature,  $T_c$ , is

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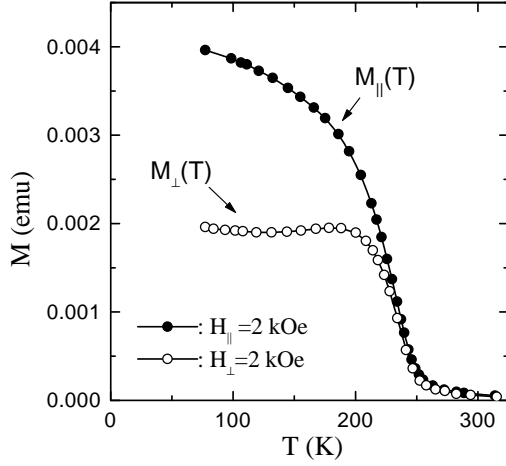


Figure 1. Temperature dependences of the magnetization of the film studied in the directions parallel and perpendicular to the film plane.

found to be about 250 K. The  $M_{\parallel}(T)$  behaviour is quite common for ferromagnetic (FM) metals. At fairly high field used, 2 kOe, the  $M_{\parallel}(T)$  curve is found to be well above the  $M_{\perp}(T)$  curve. It is reasonable to suppose that this is determined mainly by the shape anisotropy. Closer inspection shows, however, that  $M_{\perp}(T)$  behavior cannot be attributed solely to the shape-anisotropy effect:  $M_{\perp}(T)$  and  $M_{\parallel}(T)$  are practically equal in rather broad temperature range below  $T_c$ , then (going to lower temperature) the  $M_{\perp}(T)$  curve goes rather abruptly well below the  $M_{\parallel}(T)$  curve and becomes non-monotonic with a pronounced increase in  $M_{\perp}(T)$  at low temperatures. These  $M_{\perp}(T)$  features can be caused by the strain-induced magnetic anisotropy due to the film-substrate interaction. This guess is supported by the XRD study which has revealed that the film has an out-of-plane tensile strain. For materials with the positive magnetostriction this must favours an out-of-plane easy magnetization.

The temperature dependence of the resistivity,  $\rho(T)$ , is non-monotonic (Fig. 2) with a maximum at  $T \approx 250$  K and a minimum at  $T \approx 107$  K.  $\text{La}_{0.5}\text{Sr}_{0.5}\text{CoO}_{3-\delta}$  samples with fairly perfect crystalline structure and  $\delta$  close to zero are

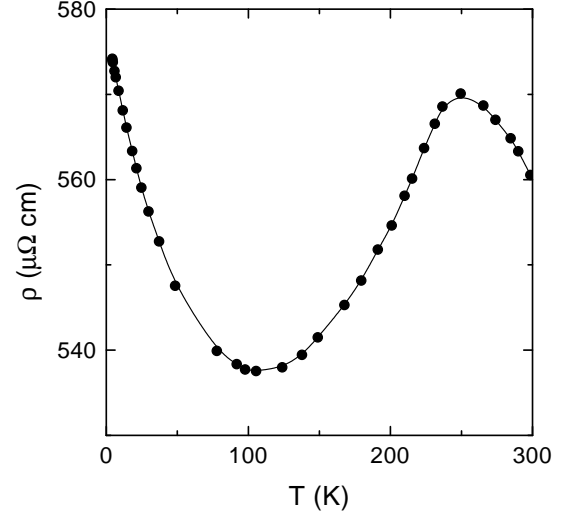


Figure 2. Temperature dependence of the film resistivity.

known to be metallic ( $d\rho/dT > 0$ ) in the whole range below and above  $T_c$  [2]. The  $\rho(T)$  behaviour in Fig. 2 reflects inhomogeneous structure of the film and some oxygen deficiency. Due to the last factor, the hole concentration is less than a nominal one (at  $\delta = 0$ ). This is responsible for a resistance peak at  $T = 250$  K which is common for low-doped samples with  $0.2 \geq x \geq 0.3$  [2]. The low temperature resistance minimum is typical for systems of FM regions (grains or clusters) with rather weak interconnections. The inhomogeneous structure can be determined by technological factors of sample preparation (causing the polycrystalline structure with rather high tunneling barriers between the grains) or by the phase separation into the hole-rich and hole-poor phase [1,2]. For an extended discussion of these points for cobaltate films see reference [5].

The MR is found to be anisotropic. The absolute values of negative MR in fields parallel to the film plane are considerably above those in perpendicular fields (Fig. 3). This MR anisotropy takes place only in FM state and disappears for  $T > T_c$  (Fig. 3). An increase in MR with decreasing temperature (in the range well below  $T_c$ ) is one more indication of poor enough connectivity between

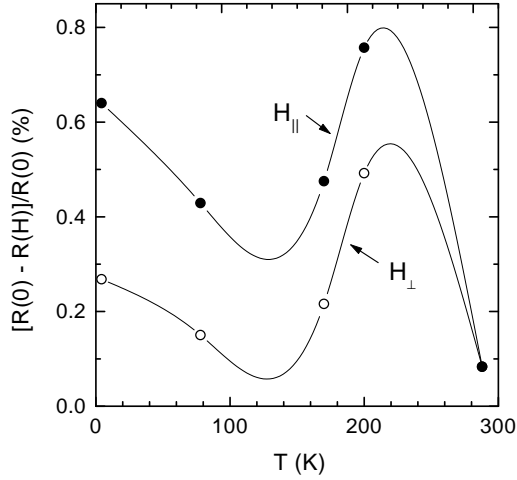


Figure 3. Magnetoresistance at  $H = 20$  kOe for fields parallel and perpendicular to the film plane.

the FM grains (or clusters) in the film.

The data presented in Fig. 3 are pertaining to negative MR for fairly high fields. In general, the MR curves are hysteretic and have specific features in low-field range (Fig. 4). Actually, their behaviour correlates with that of magnetization curves. In particular, the field  $H = H_p$ , at which MR has a peak (Fig. 4), corresponds to value of the coercive force ( $H_c$ ). The value of  $H_p$  decreases with increasing temperature and goes to zero with approaching  $T_c$ . The magnitude of positive MR in the low-field range,  $\Delta R(H_p) = [R(H_p) - R(0)]/R(0)$ , is some measure of the remanent magnetization.

We found that  $H_p$  and  $\Delta R(H_p)$  depend on the field direction and reflect in this way the magnetization anisotropy. In particular, at  $T \simeq 4.2$  K the value of  $H_p$  in the out-of-plane field is less than that in the in-plane field, and  $\Delta R(H_p)$  value is higher for the out-of-plane field direction. The opposite relations (that is, lesser  $H_p$  values and higher  $\Delta R(H_p)$  values for the in-plane field) are found for higher temperatures  $T \geq 70$  K. This implies that at low temperatures the out-of-plane magnetization is favoured, whereas at higher temperatures the in-plane magnetization

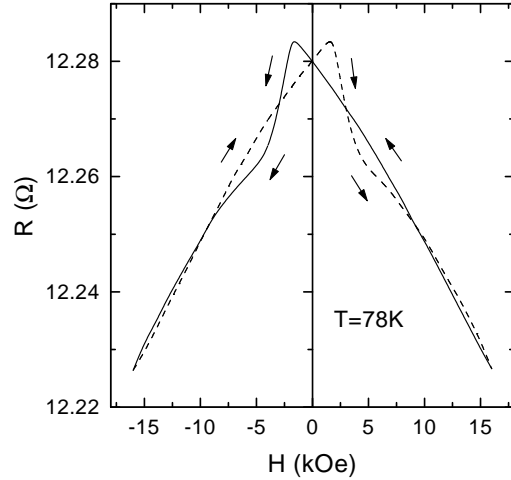


Figure 4. Magnetoresistive hysteresis. Field is parallel to the film plane and perpendicular to the transport current.

becomes dominant. The pronounced increase in  $M_{\perp}(T)$  at low temperatures (Fig. 1) supports additionally this suggestion. All these are doubtless indications of the temperature-driven spin reorientation transition which is a result of competition between the shape anisotropy and the strain-induced anisotropy. This transition has been studied intensively for films of common FM metals (see, e. g. [6]), but was never mentioned for manganite or cobaltate films.

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